MANUFACTURING AND NDE OF LARGE COMPOSITE STRUCTURES FOR SPACE TRANSPORTATION AT MSFC

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Non-Destructive Evaluation Team

NASA VISION-Earth to orbit, Safety, cost.

- **Shuttle upgrades**
- **RLVs-single stage to orbit, reusable stages, quick turnaround**

Challenges (Increase safety - reduce cost)

- **Design Considerations: Size, weight, reusability, and environment**
- **Quality Assurance: Process control, reliability, and inspectability Contamination issues**
- **Service: In-flight, Depot maintenance-Low cost quick turnaround.**

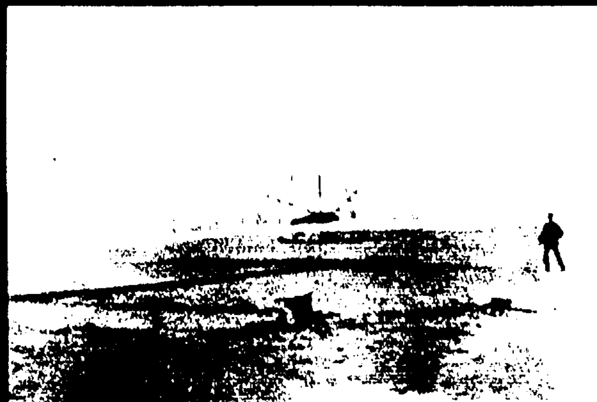
MSFC Manufacturing for Launch Vehicles

- **Filament winding, Fiber/tape placement, hand-lay up, bonded joints, Autoclave/Oven cure**
- **E-beam cure of composites**
- **Friction Stir Welding, Plug Welding**

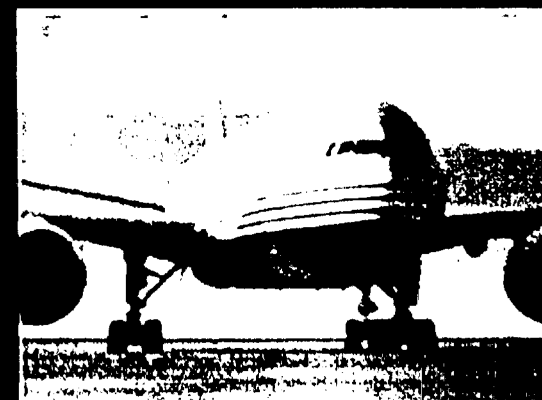
MSFC NDE Vision

- Increased resolution CT
- Field CT or Laminography
- New UT and resonant tests
- Laser UT-of large components
- IR video based inspections
- Distributed fixed or imbedded sensors and processors

Summary


Wright Flyer (1903)

6 1/2 Generations of Airplanes in a Century

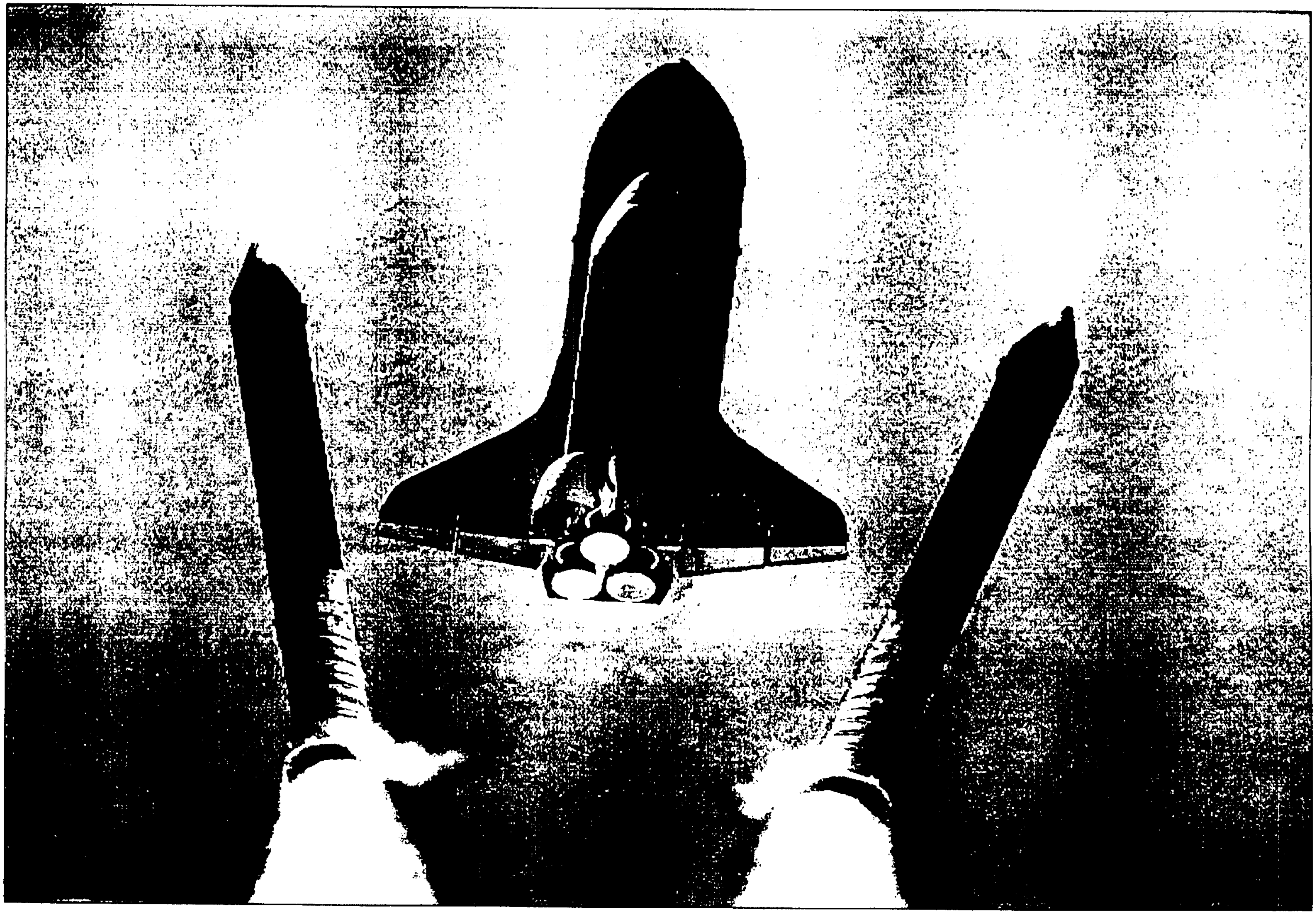

Boeing 777 (Today)

1st Generation
Reusable Launch Vehicle
(1981 – Today)

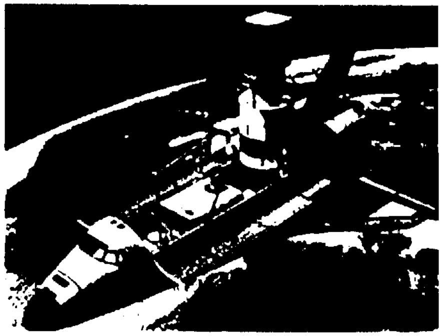
We Must Take the Next Steps Towards Safe, Routine Space Travel

STD5429

Shuttle Safety Upgrades



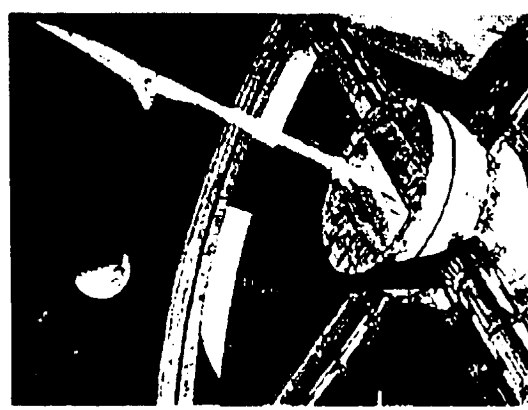
Generations of Reusable Launch Vehicles



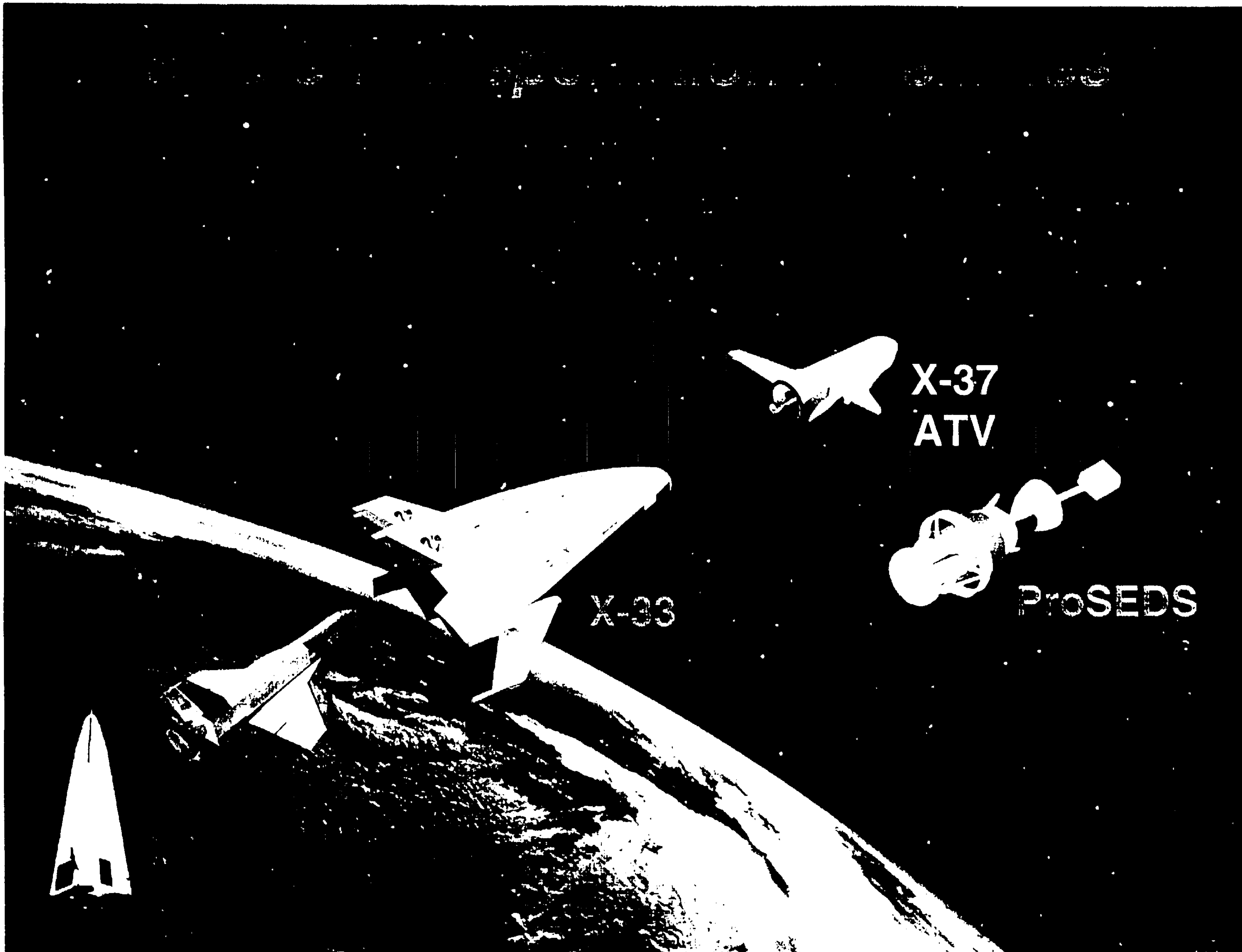
Today: Space Shuttle
1st Generation RLV
- Orbital Scientific Platform
- Satellite Retrieval and Repair
- Satellite Deployment

2010: 2nd Generation RLV
Space Transportation
- Rendezvous, Docking, Crew Transfer
- Other on-orbit operations
- ISS Orbital Scientific Platform
- 10x Cheaper
- 100x Safer

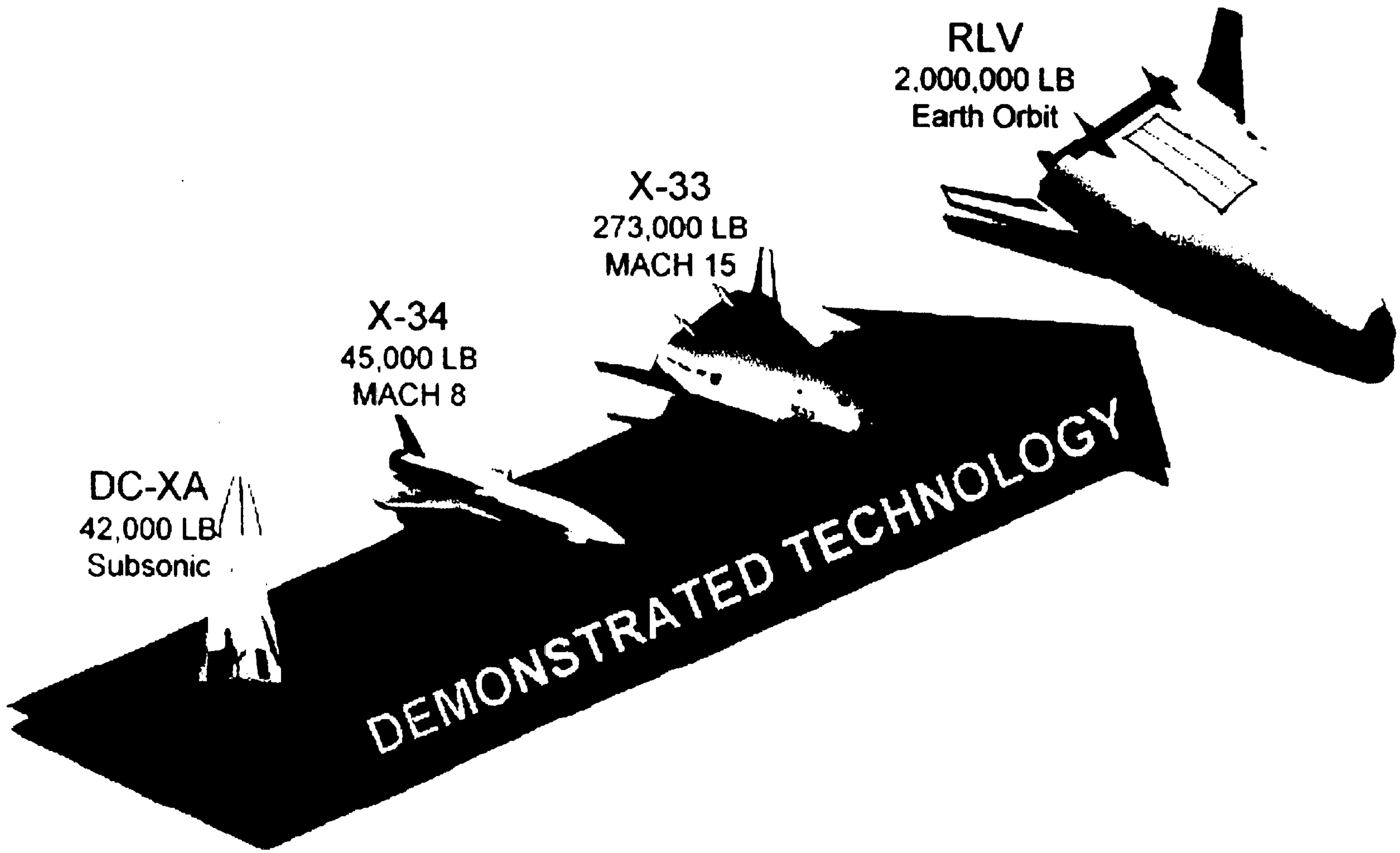
2025: 3rd Generation RLV
- New Markets Enabled
- Multiple Platforms / Destinations
- 100x Cheaper
- 10,000x Safer



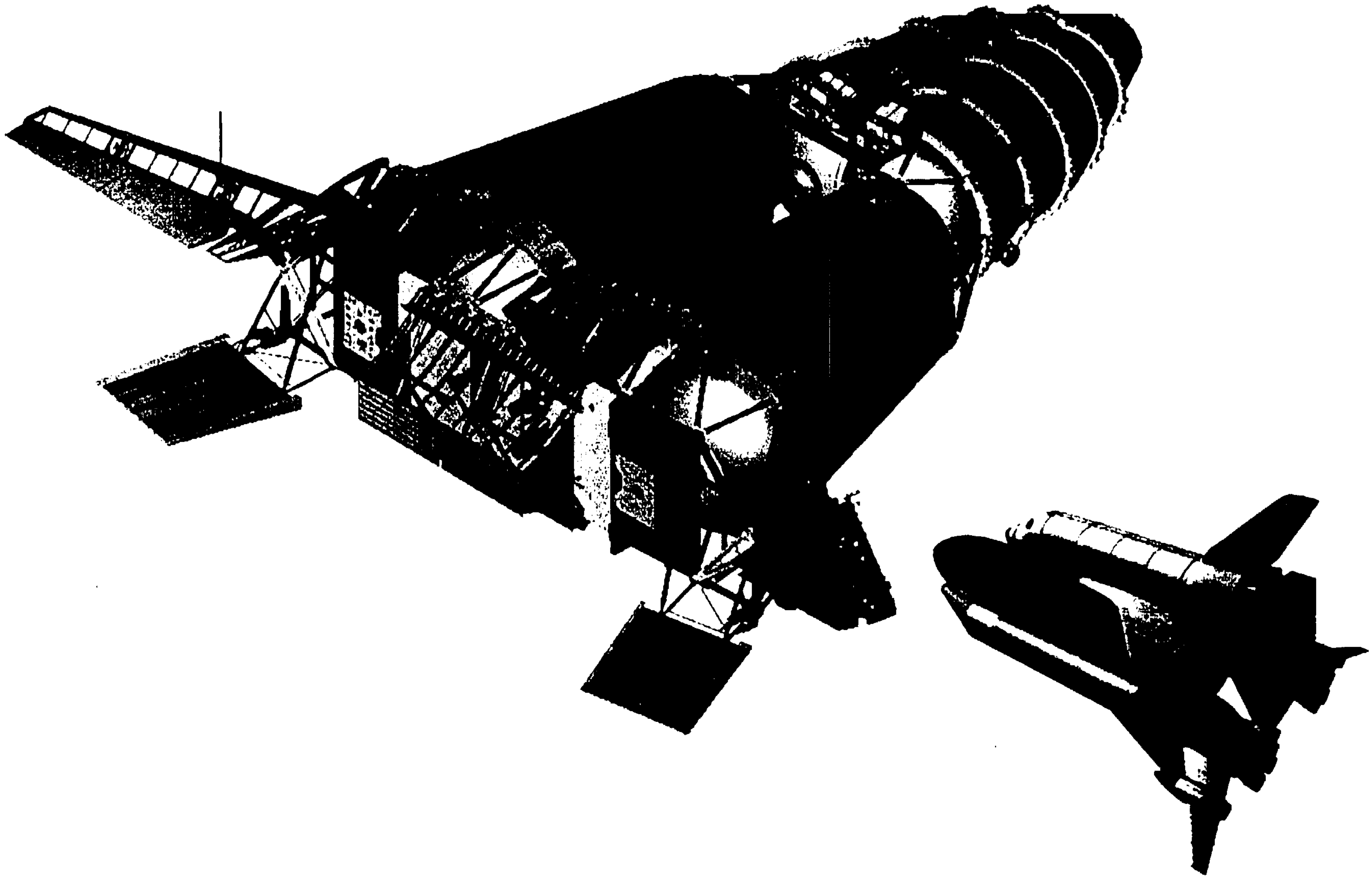
2040: 4th Generation RLV
- Routine Passenger Space Travel
- 1,000x Cheaper
- 20,000x Safer


X-37
ATV
ProSEDS
X-33

RLV Technology Demonstration Path



Second Generation...

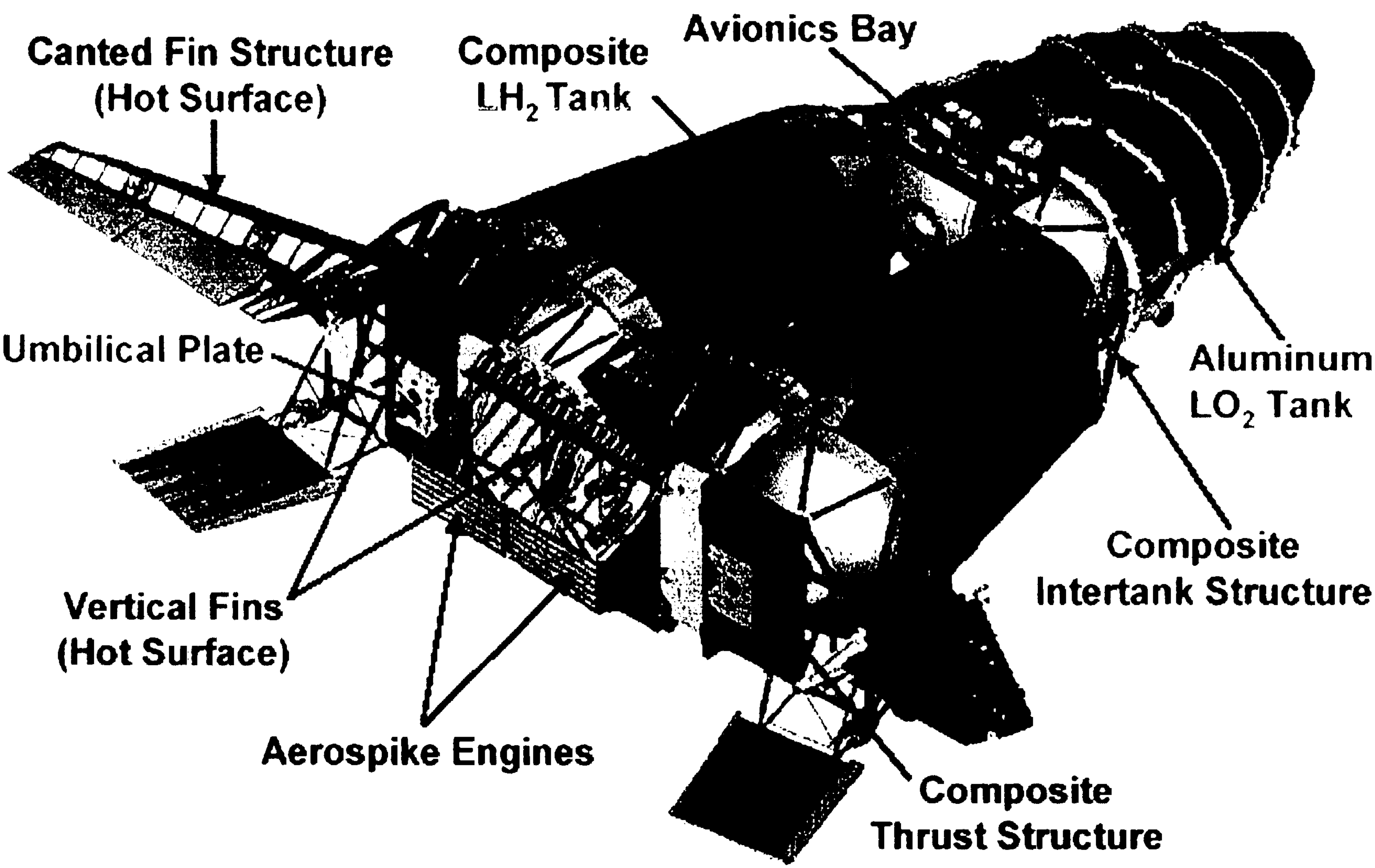


Key NASA Requirements

- **Safety/Reliability Goals**
  - **Probability of Loss of Crew (LOC): 1 in approximately 10,000 missions (2nd gen)**
  - **Probability of Loss of Vehicle (LOV): 1 in approximately 1,000 missions (2nd gen)**
    - Note: NASA is open to alternate methods of trading the LOV goal to address insurance requirements while remaining committed to the LOC goal
  - **Crew survivable abort capability throughout the flight profile**
  - **Probability of LOC/LOV: 1 in approximately 1,000,000 missions (3rd gen)**
  - **In addition, NASA is interested in addressing the feasibility and impact of providing:**
    - Capability for safe orbit insertion with single main engine out from the pad;
    - Crew on-orbit rescue capabilities; and
    - Descent and/or landing abort

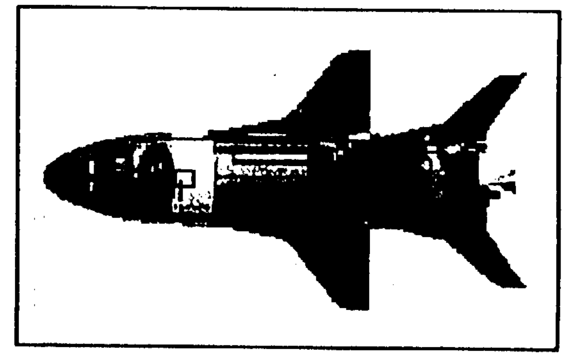
- **Cost Goals**
  - **Reduce the recurring operational cost to NASA of the space transportation architecture to $1,000 per pound of payload (2nd Generation)**
  - **Reduce the recurring operational cost of the space transportation architecture to $100 per pound of payload (3rd Generation)**
  - **Consideration of non-recurring costs will be included in studies**

X-33 Elements



Future-X Pathfinder Projects and Experiments

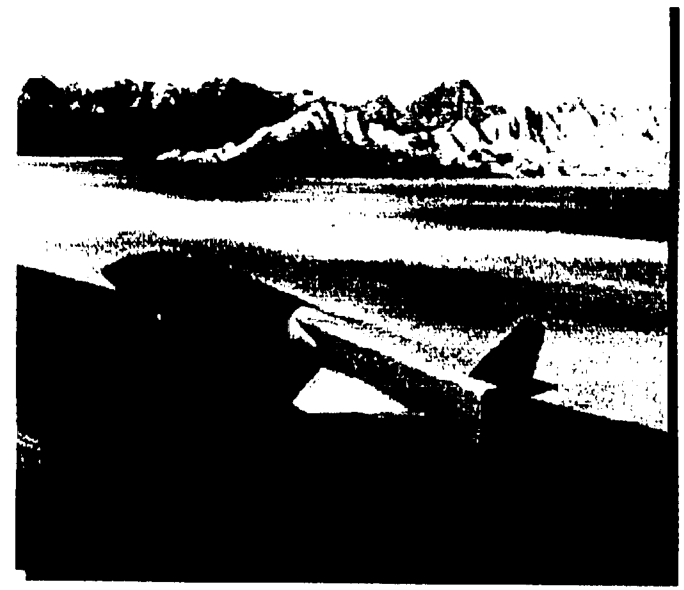
- **Flight Demonstrator Vehicles**
  - X-34 Rocket Plane - Mach 8 technology testbed
  - X-37 Space Plane - Orbital technology testbed
- **Flight Experiments**
  - Flown on X-34:
    - GAMMA-TITANIUM ALUMINUM-BASED TPS (ALENIA AEROSPACE)
    - ADVANCED C/SIC TPS (ESA-DAIMLER-BENZ)
    - MECHANICALLY ATTACHED FLEXIBLE TPS (BOEING)
    - ENCAPSULATED WATERPROOF 2500F CMC TPS (MDA [Now BOEING])
    - FLIGHT TEST DETAILED SPECIMENS IN CERTIFIED HOLDER (MDA [Now BOEING])
    - ACTIVE DAMAGE INTERROGATION HEALTH MONITORING SYSTEM (MDA [Now BOEING])
    - ACOUSTIC EMISSION HEALTH MONITORING SYSTEM (BOEING)
    - AUTONOMOUS ABORT LANDINGS (DRAPER LAB)
    - INTEGRATED VEHICLE HEALTH MANAGEMENT (IVHM) (NASA AMES)
    - COMPOSITE LOX TANK (LOCKHEED-MARTIN)
  - 40 Embedded or Carry-On Experiments Baselined for X-37



Focus Area Technical Goals

New RLV Technologies Embedded in Vehicle Design

- **Demonstrate technologies throughout flight profile**
  - Subsonic and hypersonic flight
  - Capable of powered flight to at least 250k ft
  - Capable of attaining Mach 8
- **Capable of autonomous flight operations**



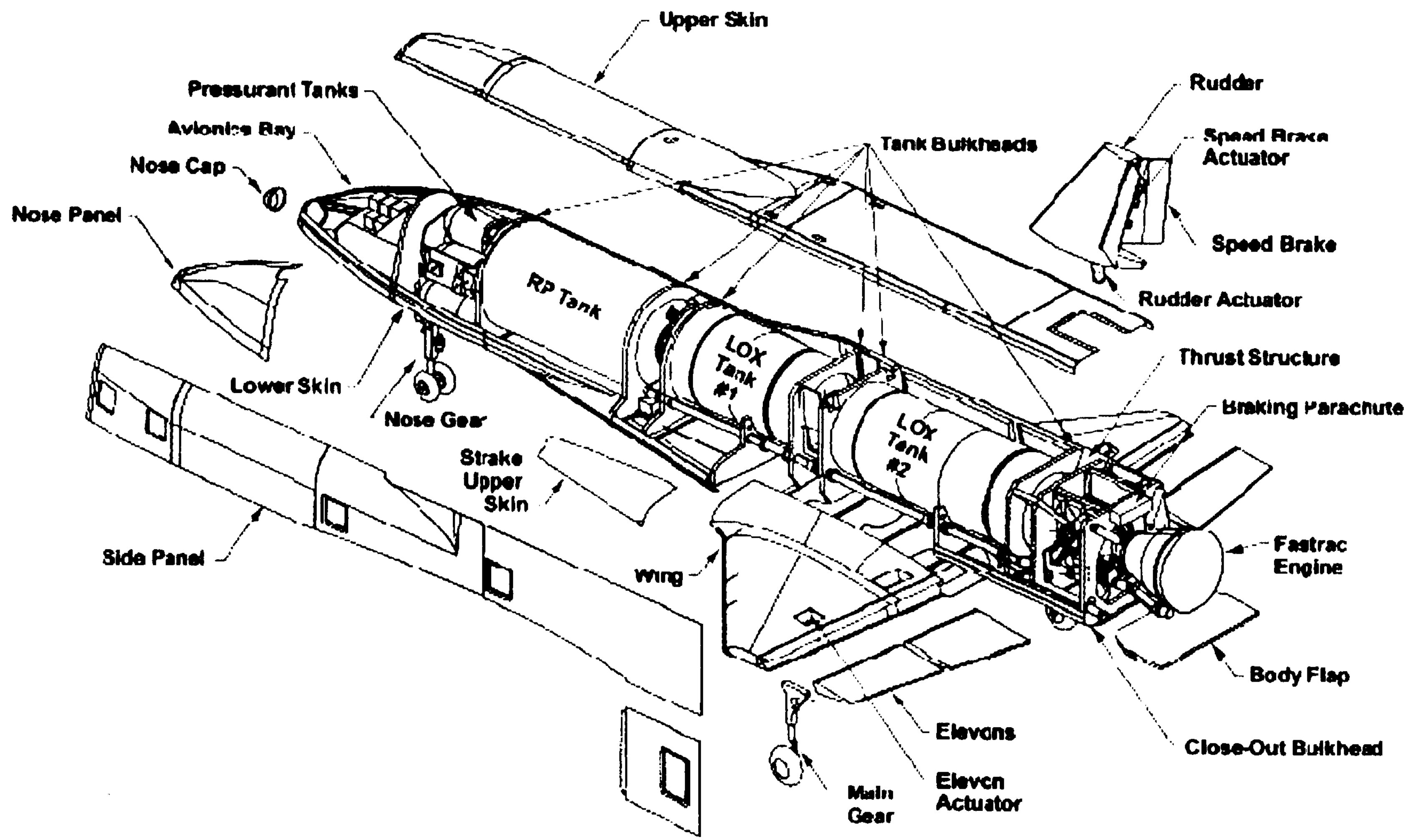
Investigation of New Methods for Low-Cost Operations

- **Capable of demonstrating safe abort**
- **Capable of 25 test flights over a period of 1 year (OMB metric)**
- **Low cost operations**
  - Small work force
  - Nominal 2-week turnaround
  - Surge capability of 2 flights within 24 hours
  - Capable of attaining average recurring flight cost of $500k
- **Operation in RLV-type environments**
  - Flights through rain and fog
  - Landings with cross winds of 20 knots or greater

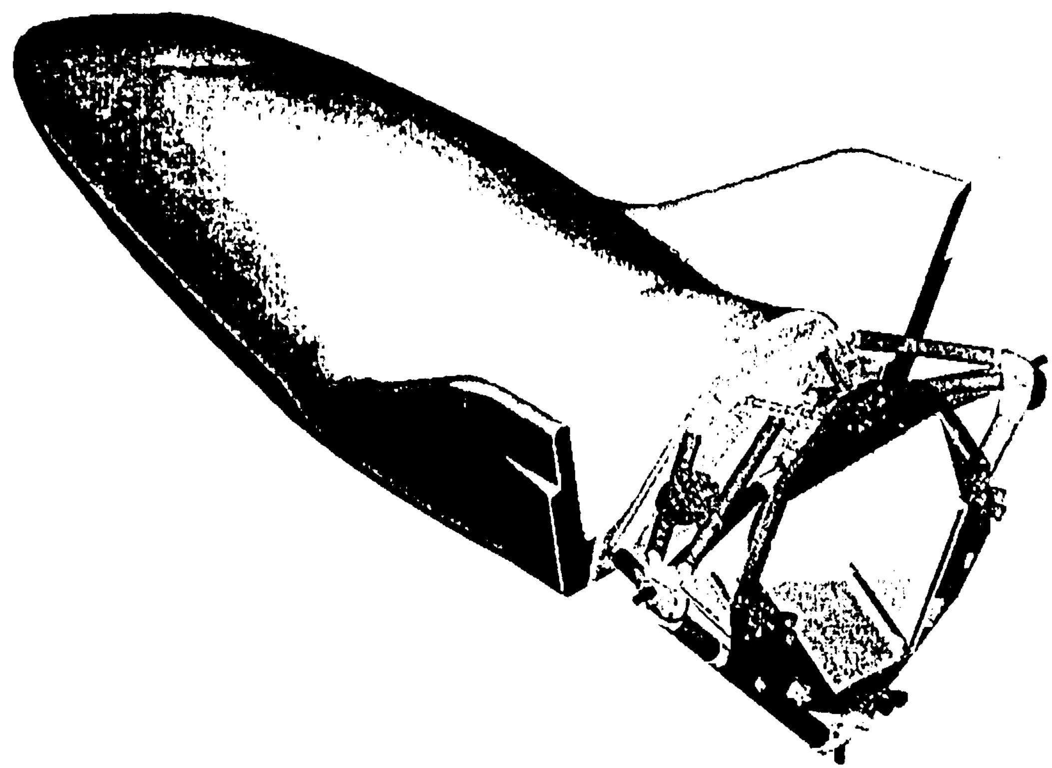
Testbed for Hosted RLV and Hypersonic Experiments

- **On-board instrumentation for testing embedded technologies**
- **Small area for "carry-on" experiments**

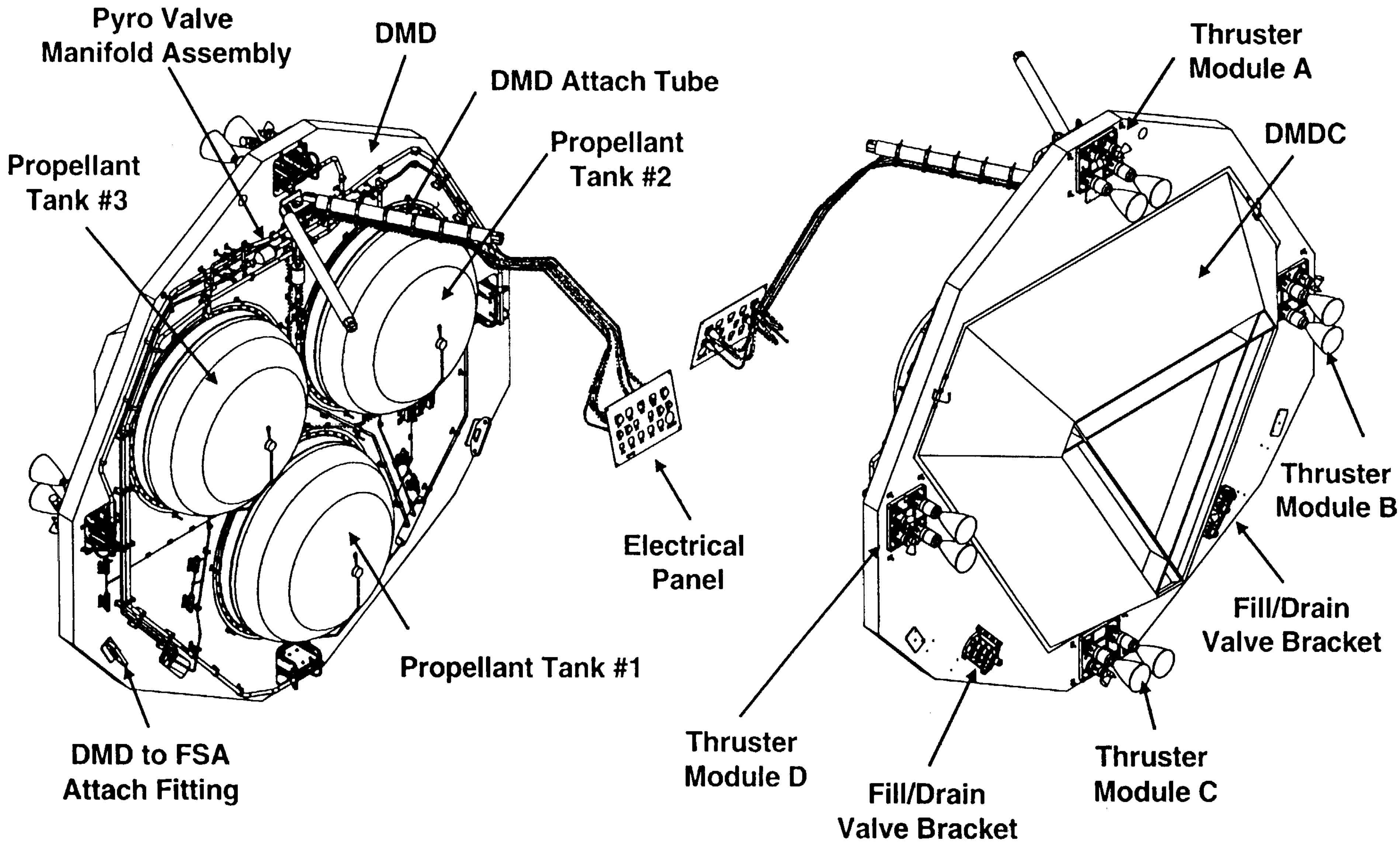
X-34 Expanded View



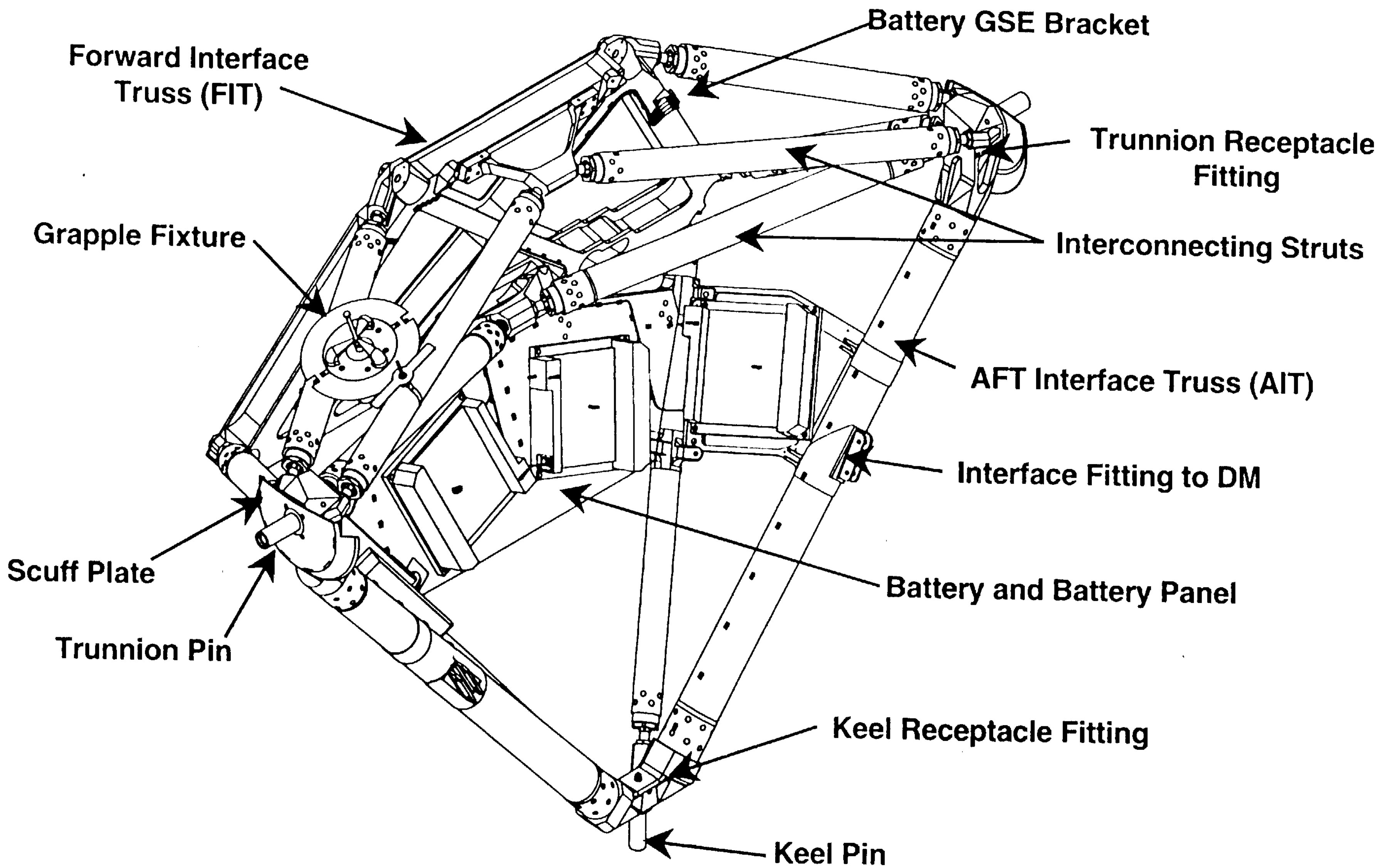
X-38 Spacecraft with DPS



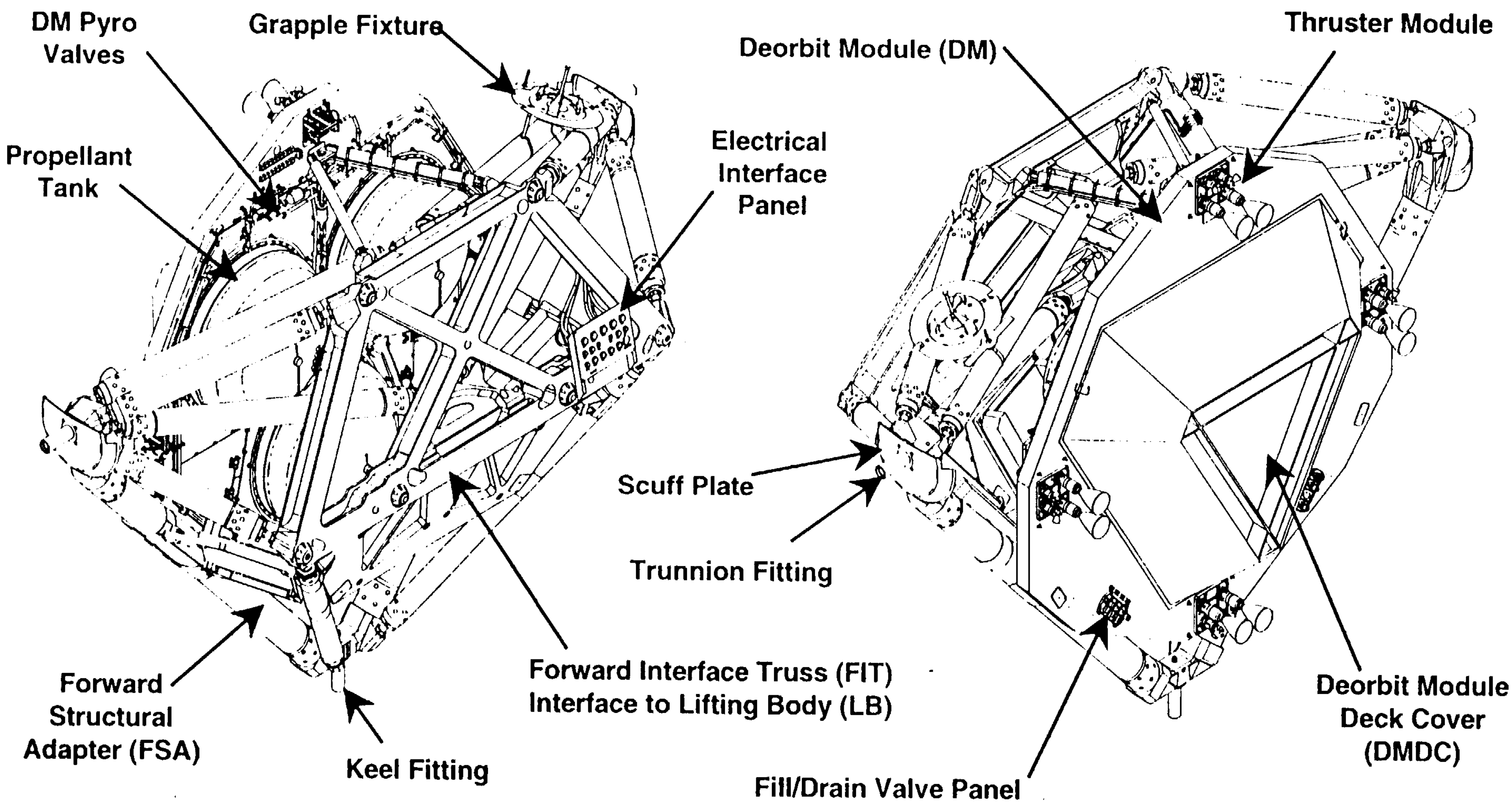
Deorbit Module (DM) CDR Design



Forward Structural Adapter (FSA) CDR Design

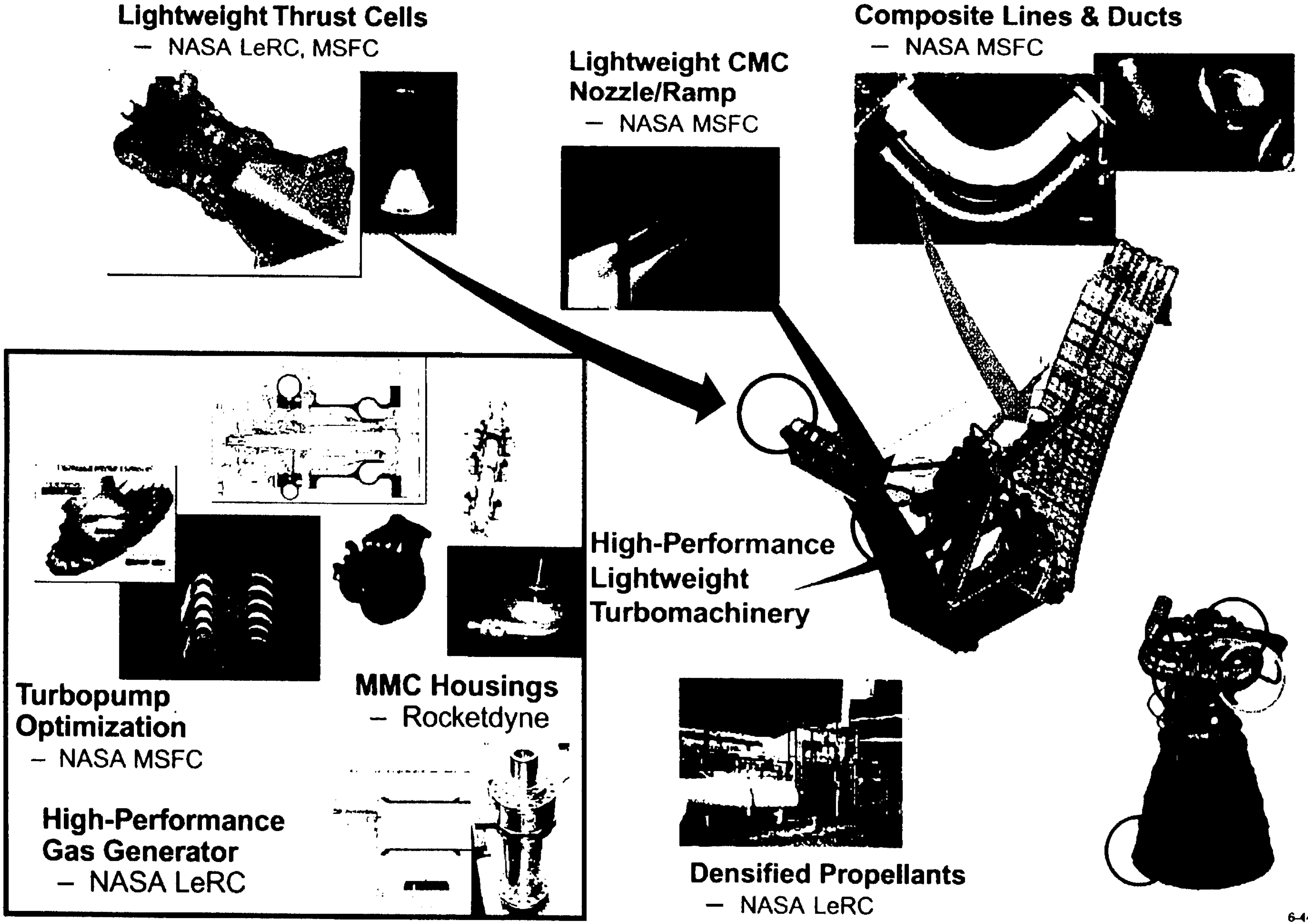


X-38 DPS CDR Design



DPS Without Thermal Blankets Shown

RLV Focused Propulsion Technologies



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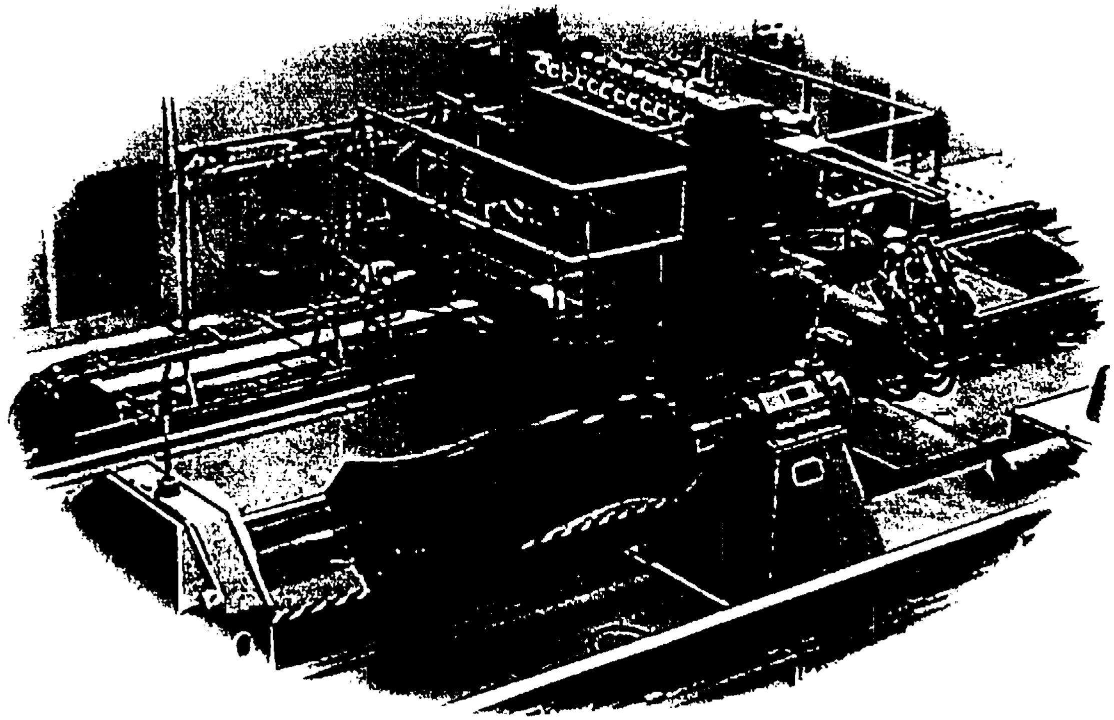
CHALLENGES IN TECHNOLOGY
Immediate Trends

- Primary structure, Aerostructure, and Tanks
  - -large, complex construction, bonded joints, new fabrication methods, new fiber and matrix systems or metal alloys
- Turbomachinery-components of new materials
  - ceramic composite blisks
  - composite valve bodies
  - composite plumbing
  - metal matrix components
- Composites for nozzles
- Health monitoring required
- Critical Design Requirements
  - Materials used for strength critical design, diffusion requirements, thermal requirements



Fiber Placement Machine

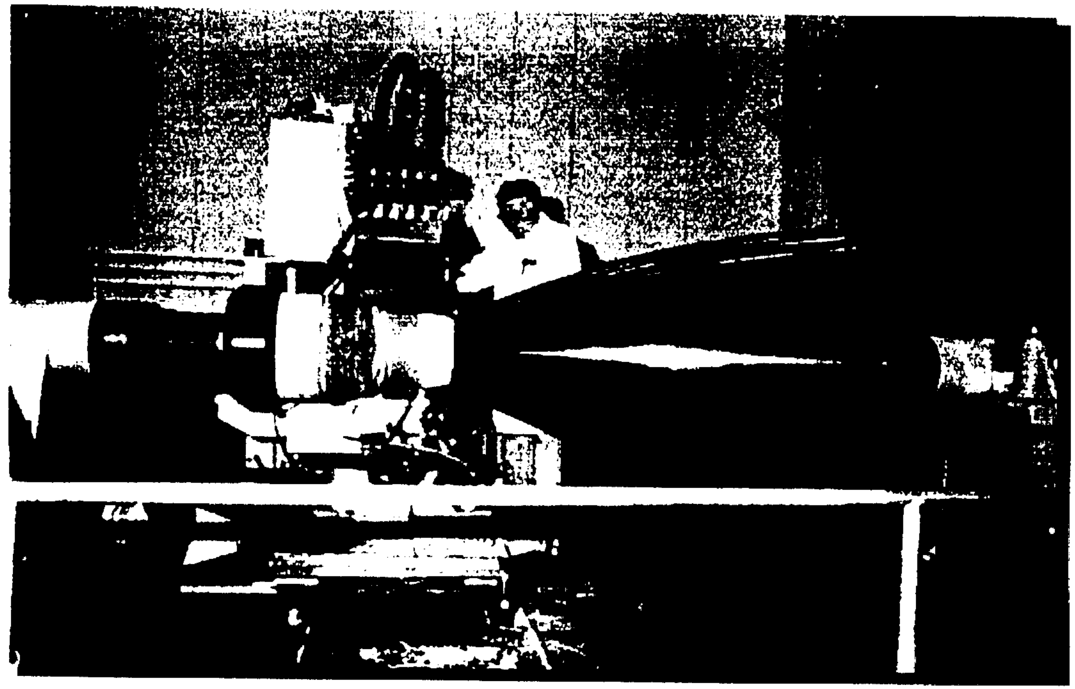
Description: Most advanced process available, Utilizes 24 individual tow/tape material, machine has seven major axes of motion

Capability: 3′ x 20′ x 20klbs; complex 3-D shapes with concave and other asymmetrical configurations
differential tow payout speed and compaction results in uniform part thickness; analysis, simulation, and machine programming are all administered within one software environment

Filament Winding

Description: Most widely used automated process, Utilizes up to 12 individual tow/tape material, machine has five major axes of motion

Capability: 4' x 12' x 8klbs; cylindrical, spherical, and other symmetrical geometry's, very accurate high speed material placement



Nozzle Tapewrapping Machine

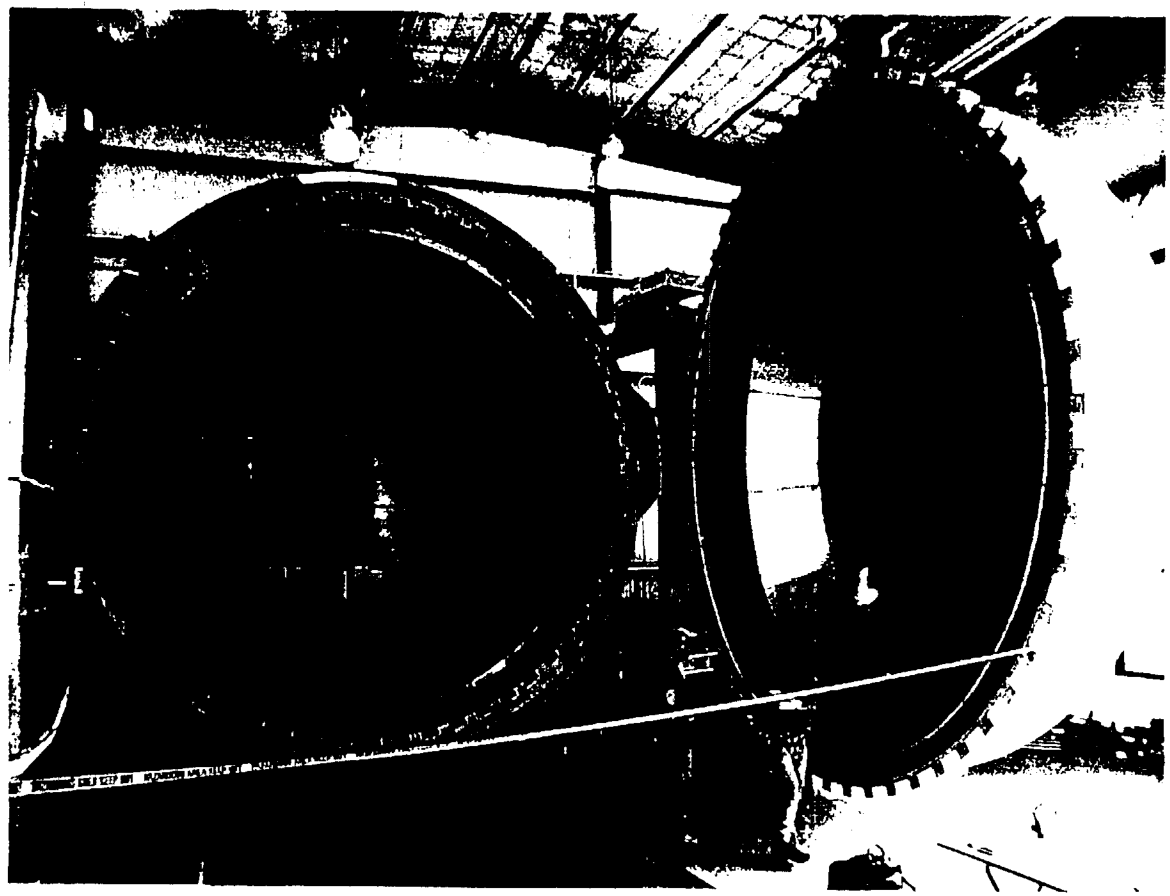
Description: Specialized equipment used for fabrication of rocket motor/engine nozzle and combustion chamber components, uses broadgood/tape materials

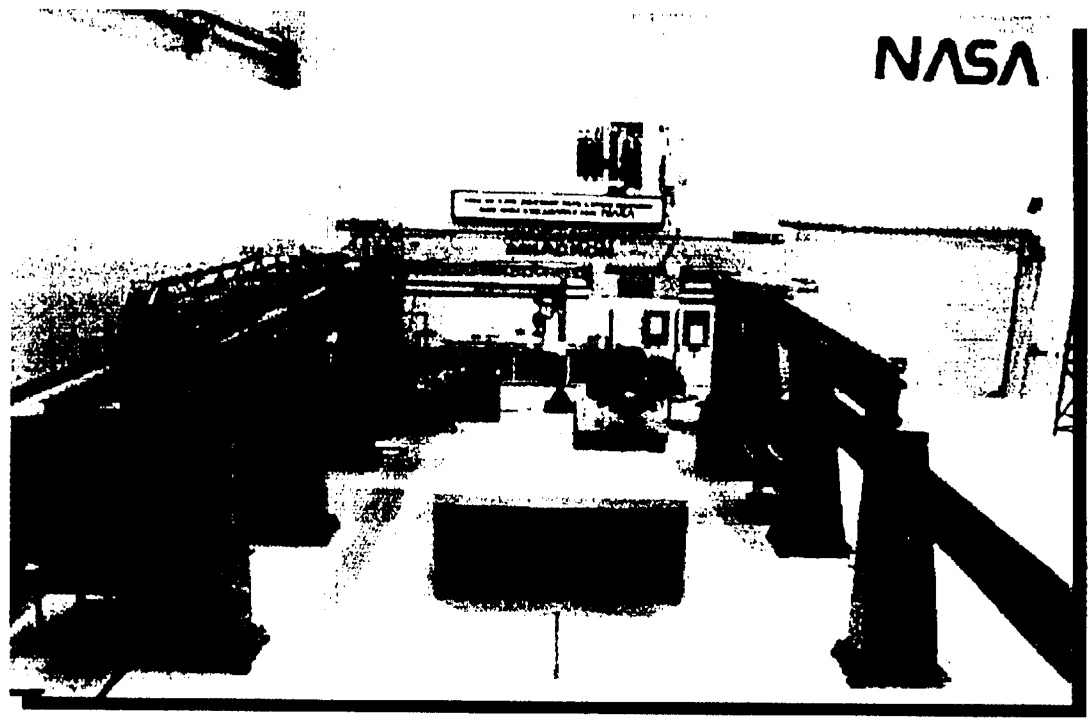
Capability: 5′ x 5′ x 10klbs; cylindrical, conical, and other symmetrical geometry's,

Autoclave

Description: Pressure vessel/oven used to provide up to 350 psi and 650°F.

Capability: Four at MSFC; 18'x20', 12'x30', 9'x12', 5'x9'. Computer control of temperature and pressure.



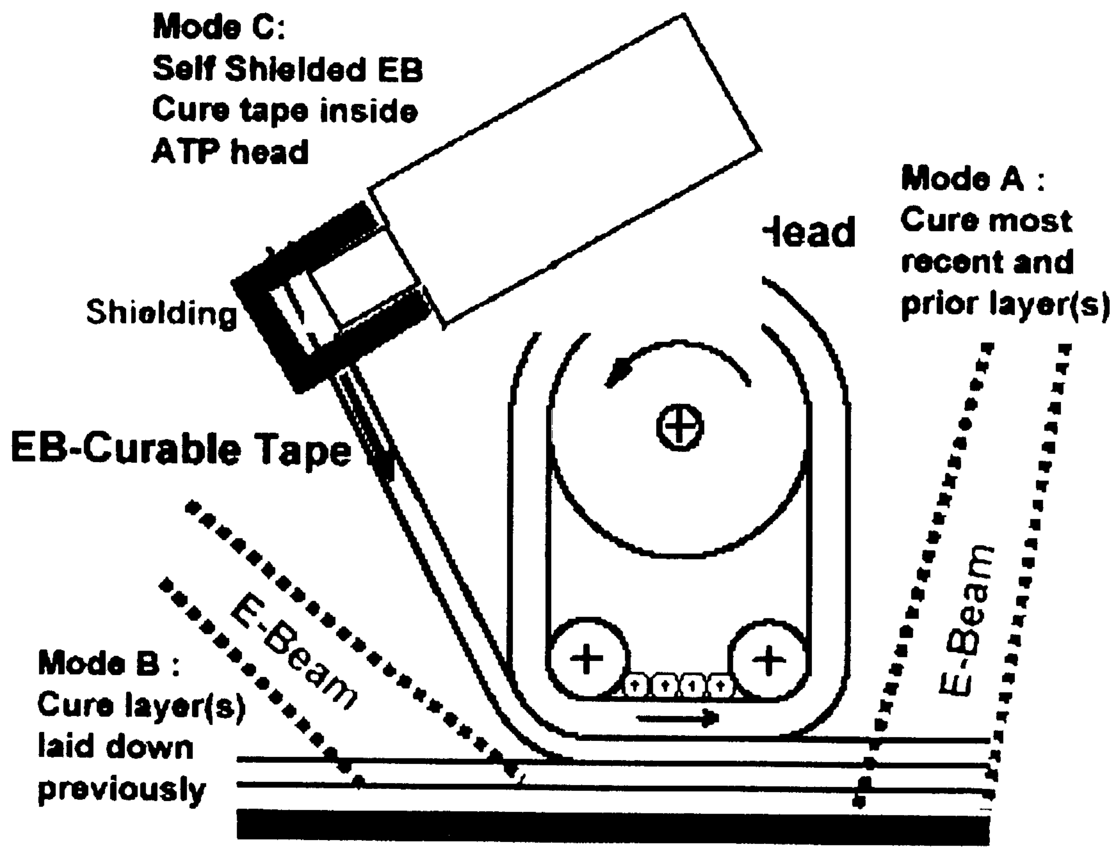


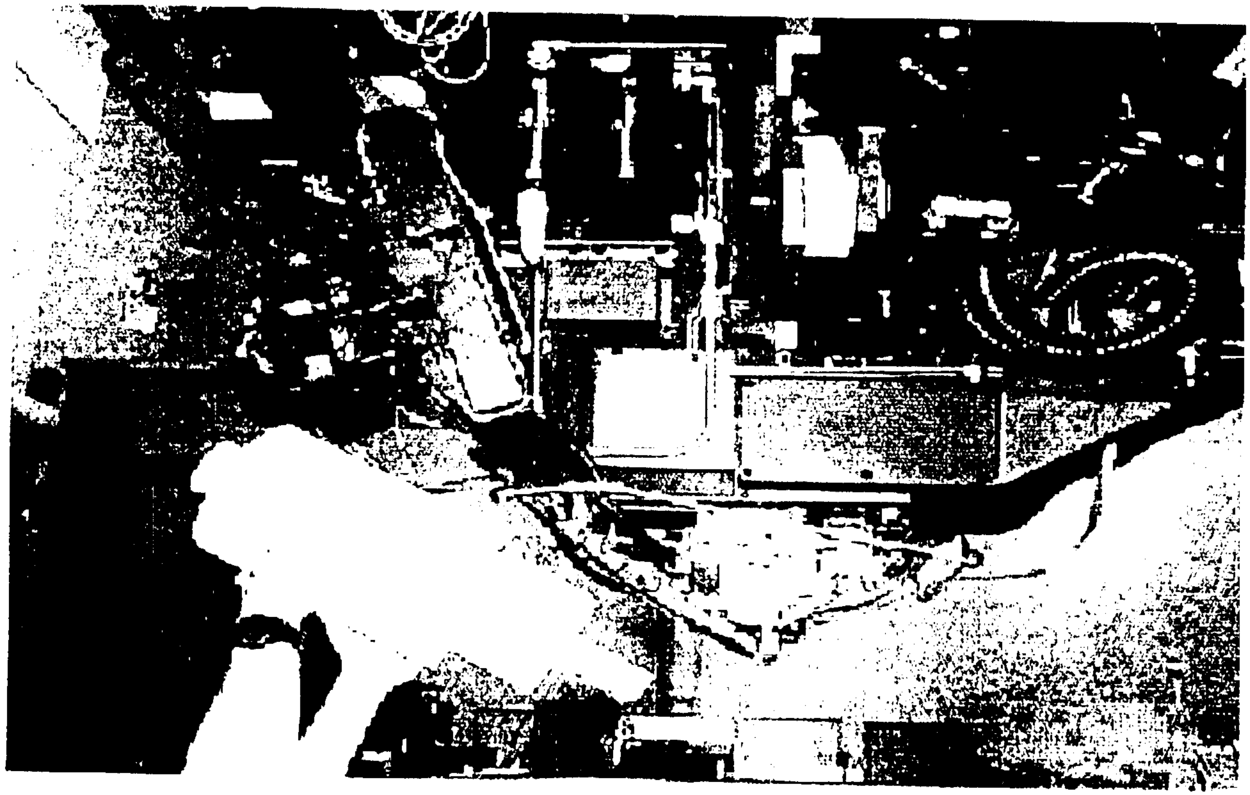
Tape Laying Machine

Description: Used for Large flat or lightly contoured surfaces. Uses 3-inch tape material, machine has seven major axes of motion.

Capability: 15′ x 25′; semi 3-D shapes with concave and other asymmetrical configurations,
Very accurate high speed material placement with compaction;

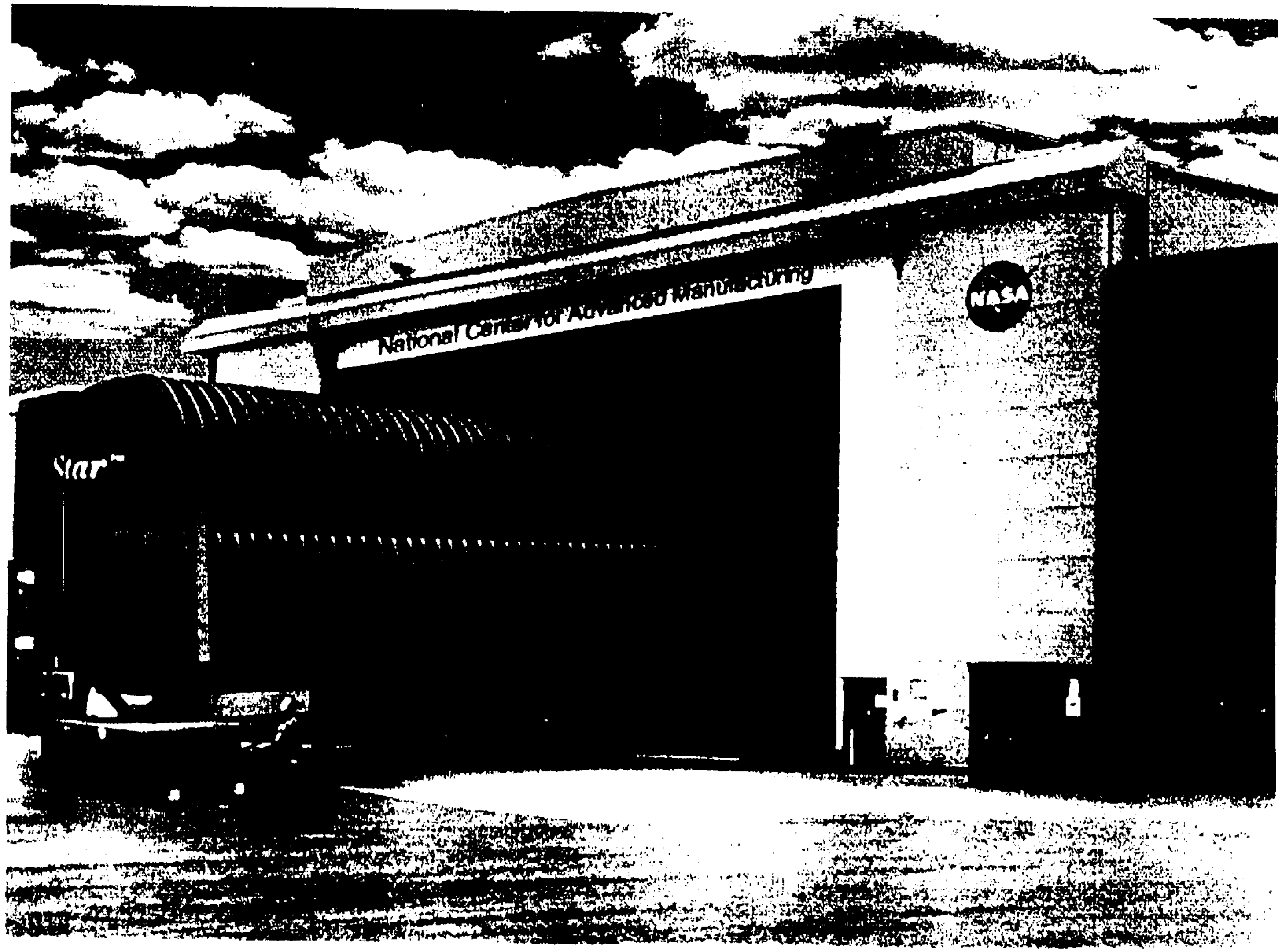
Processes Combine EB with Tape Placement





The planned attachment of the EB gun to the ATP system at MSFC.
A full-scale mockup of the EB gun is shown.

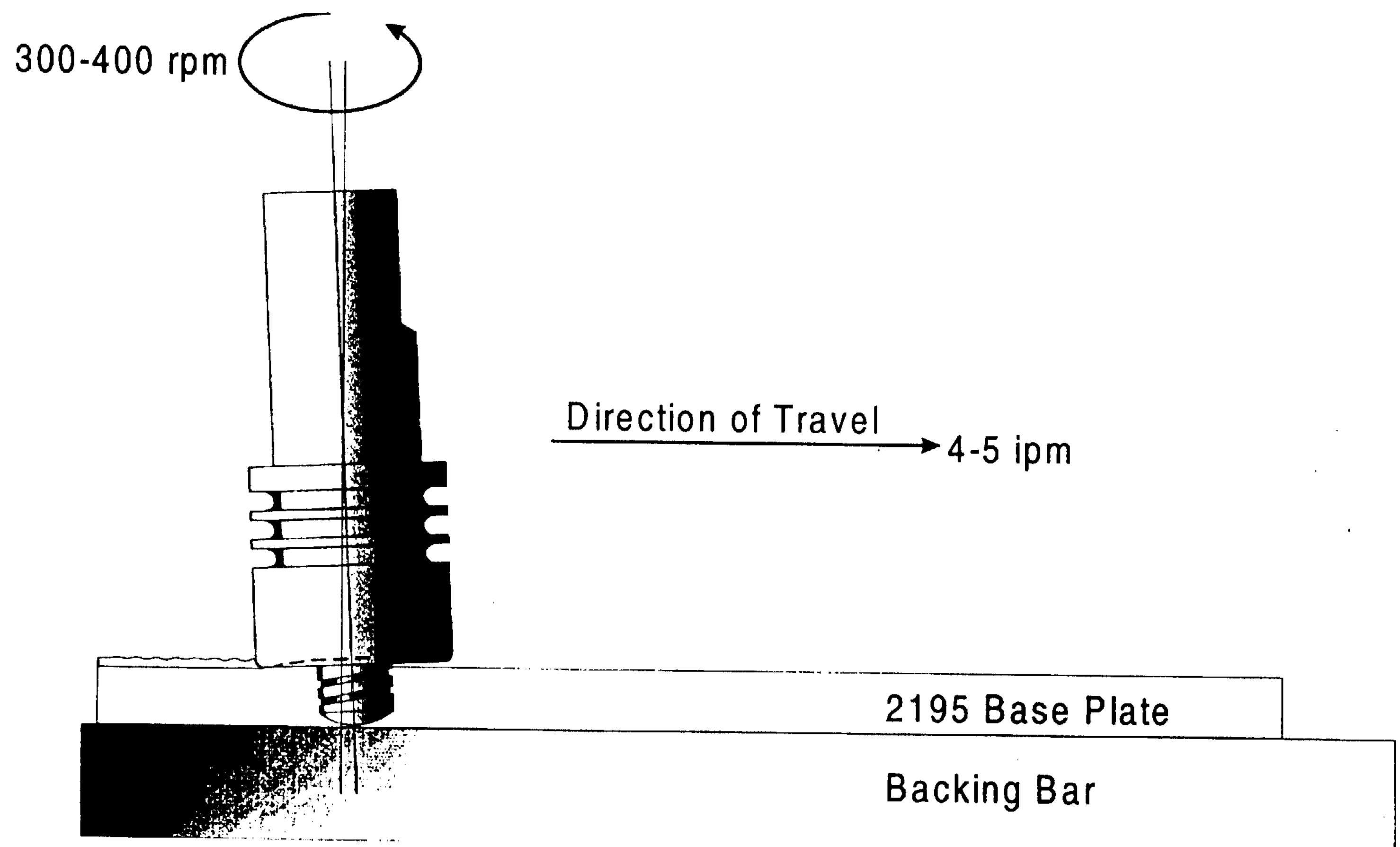
Description: development key to reducing costs, ideal for large structures, eliminates requirement for autoclave/oven



Large Composite Structures Manufacturing

Description: Development problems include insufficient experience and inadequate facilities

Friction Stir Welding of Aluminum Plate



Summary

- New materials, manufacturing processes, and increased requirements will require development of new or improved NDE methods.
- The morning and the afternoon sessions contain talks on how the technology is developing to meet the evolving NDE needs for many applications including Space Transportation..

Non-Destructive Evaluation of Large Composite Structures

- Improve Understanding of Composite Behavior and Integrity
  - Development of NDE methods for composites - verification required for each material system, geometry and process
  - Develop standard approach for verification
    - Generate "realistic" defects: delamination, porosity, unbond, fiber discontinuities for various composite constructions
    - Characterize response signal vs. defect type for each NDE method
    - Generate POD for various composite types, defect types and NDE methods
    - Damage Tolerance Studies - correlate damage with residual strength
  - Require qualification of operator and process
  - Build process witness panels concurrent with hardware production
    - Inspect process witness panels
    - Test qualification panels

Non-Destructive Evaluation of Large Composite Structures

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- Current Inspection Techniques (continued)
  - Computed Tomography
    - Good for detection of delamination and unbond
    - Limited to small parts, (nozzle, turbine disk), due to radiographic energy level requirements and resolution issues.
  - Shearography
    - Capable of identifying debonds and delaminations in structures
    - Depth limited by the stiffness of the material above defect

- Current Monitoring Technique
  - Acoustic Emission
    - Good for detection and location of active flaw growth
    - Requires in-depth understanding of wave propagation characteristics of material

Non-Destructive Evaluation of Large Composite Structures

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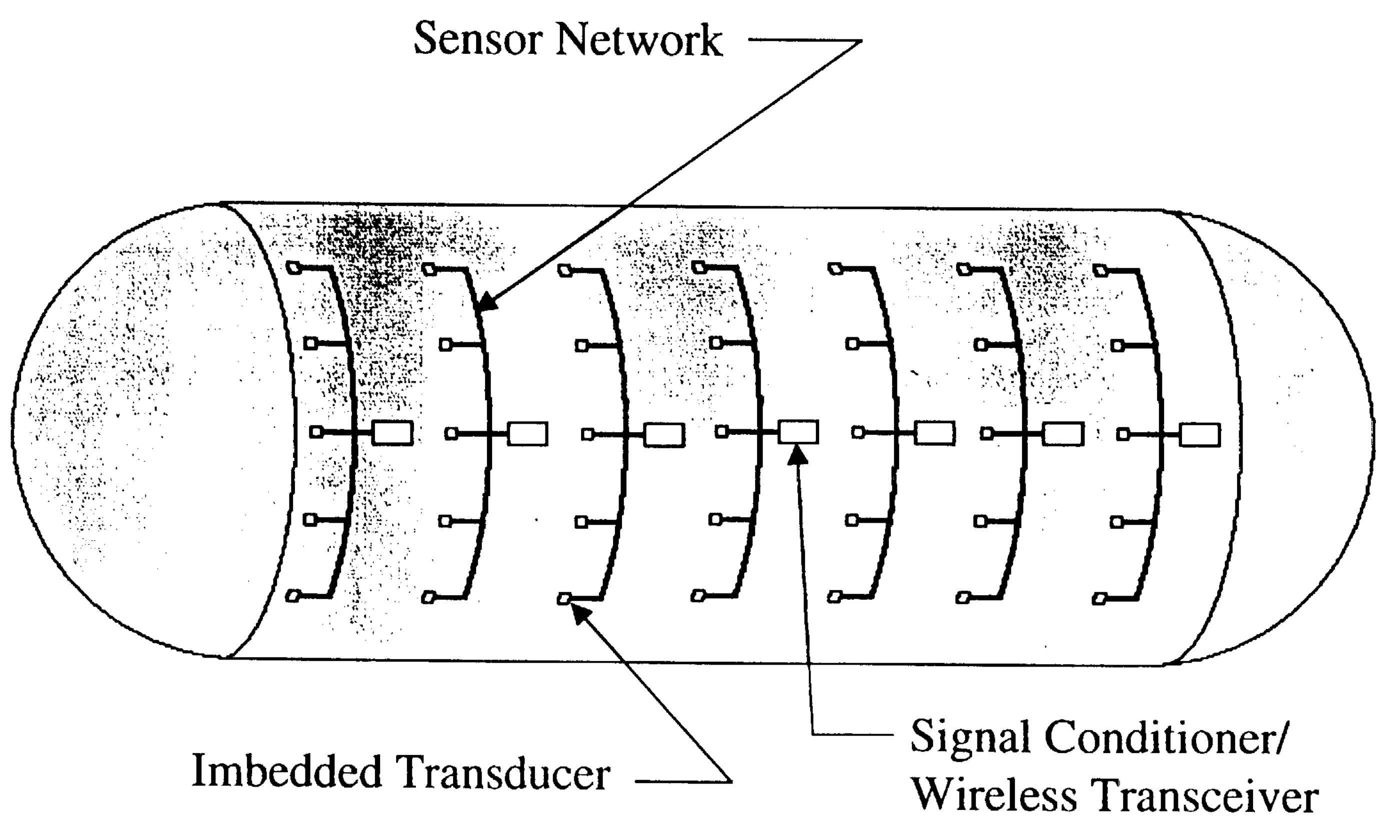
- Inspections (continued)
  - Emerging Technologies for Composite Inspection

    - NDE through Structural Health Monitoring
      - Continue research into embedded and external sensor development
        - Piezoelectric ultrasound sensors
        - Fiber optics
        - Thermocouples
        - Strain Gages
        - Acoustic Emission
      - Develop data monitoring/interpreting systems
        - Distributed, on structure, data recording and processing units
      - Investigate environmental factors: temperature, cyclic loading
      - Perform verification testing of health monitoring systems on prototype and full scale structures
      - Assess impact of sensors on structure performance

Non-Destructive Evaluation of Large Composite Structures

- Inspections (continued)
  - NDE through Structural Health Monitoring



Non-Destructive Evaluation of Large Composite Structures

- Inspections (continued)
  - Emerging Technologies for Composite Inspection
    - Laser Ultrasonics (sound generation by high power short pulse laser)
      - Demonstrated capability for detecting delamination and impact damage on honeycomb structures
      - Accommodates complex geometry (robotic drive with cad model)
      - Non-contact
      - Requires only single side access
      - Langley developing method
      - Developed for Air Force composite structures with Lockheed Martin
      - Some modes are potentially ablative

Non-Destructive Evaluation of Large Composite Structures

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- Inspections (continued)
  - Laser Ultrasonics

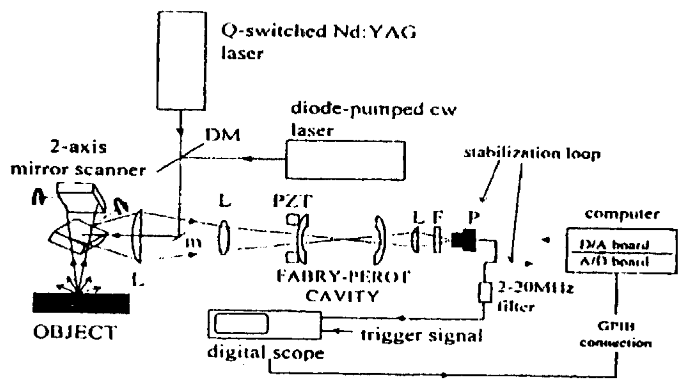

Fig. 2—Experimental setup for laser-based ultrasonic C-scan system: DM = dichroic mirror, L = lens, m = small mirror, PZT = piezoelectric transducer, F = 532-nm filter, P = amplified photodetector

Non-Destructive Evaluation of Large Composite Structures

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- Inspections (continued)
  - Emerging Technologies for Composite Inspection
    - Acousto Ultrasonics/Resonant Ultrasonics
      - Good for assessing joint integrity
      - Can be used to locate and characterize variations in material properties
      - Contact method
      - Small area coverage

Non-Destructive Evaluation of Large Composite Structures

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- Proposed Multi-Phase Tasks
    - Develop Generic Methodology for Evaluation of Composite Processes
    - Correlate NDE Response With Defect Characterization
    - Investigate Emerging Technologies for Non-Destructive Evaluation of Composite Structures
    - Continue Development and Application of Health Monitoring Systems
    - Develop "Smart" Tank Technology Test Bed

Non-Destructive Evaluation of Large Composite Structures

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- Proposed Tasks
  - Develop Generic Methodology for Evaluation of Composite Processes
    - Background Review
      - Historical Review
      - Industry Review
    - Requirements Document
      - Provisions for Process Control
      - Provisions for Damage Tolerance Testing
      - Provisions for NDE
        - In process
        - During Refurbishment

Non-Destructive Evaluation of Large Composite Structures

- Proposed Tasks

  - Correlate NDE response with defect characterization
    - Collect existing in-house data
    - Identify composite processes outside database required to support MSFC/NASA programs
      - Fabricate baseline panels for these processes
      - Perform NDE assessment of panels
      - Destructive evaluation of panels
      - Correlation of test results

  - Investigate Emerging Technologies for NDE of Composite Structures
    - Perform Feasibility Study
    - Purchase New System
    - Perform baseline testing
    - Perform component article testing

Non-Destructive Evaluation of Large Composite Structures

- Proposed Tasks (continued)
  - Continue development of health monitoring systems
    - Identify current research areas (sensors, integration, collection)
    - Define/Conduct research
    - Correlate health monitoring data with structure performance
  - Develop "Smart" Tank Technology Test Bed
    - Design "smart" tank or structure per requirements document with health monitoring system (10' x 30')
      - Structure representative of flight structure scale
      - Structure representative of flight structure geometry
      - Structure representative of flight structure process
    - Fabricate tank or structure
    - Test tank or structure